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Title: Gamma ray Holdup Measurements

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Gamma ray Holdup Measurements

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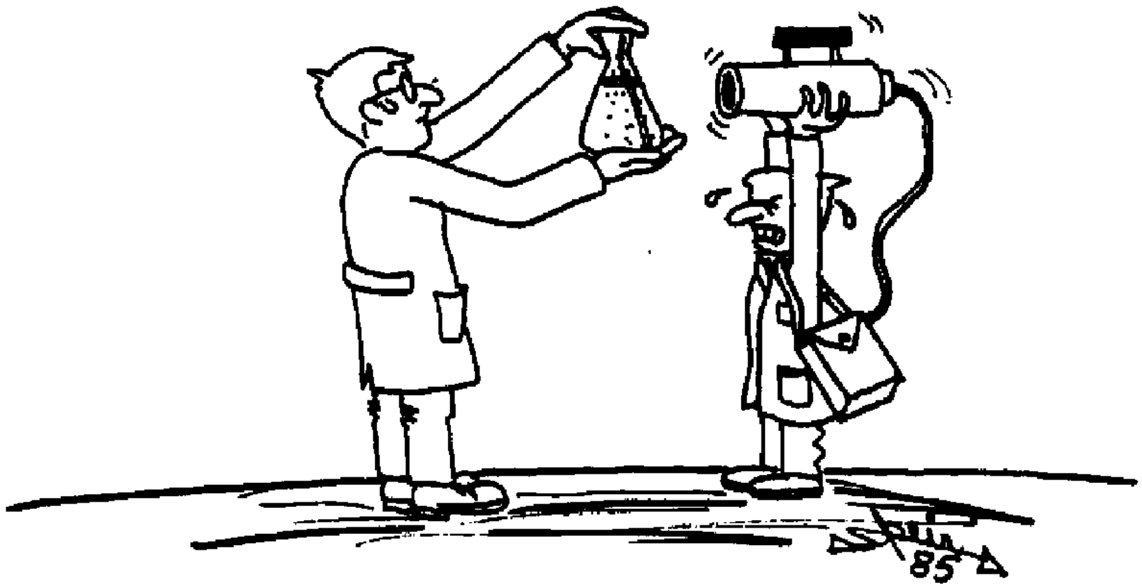
Plutonium Verification Team training

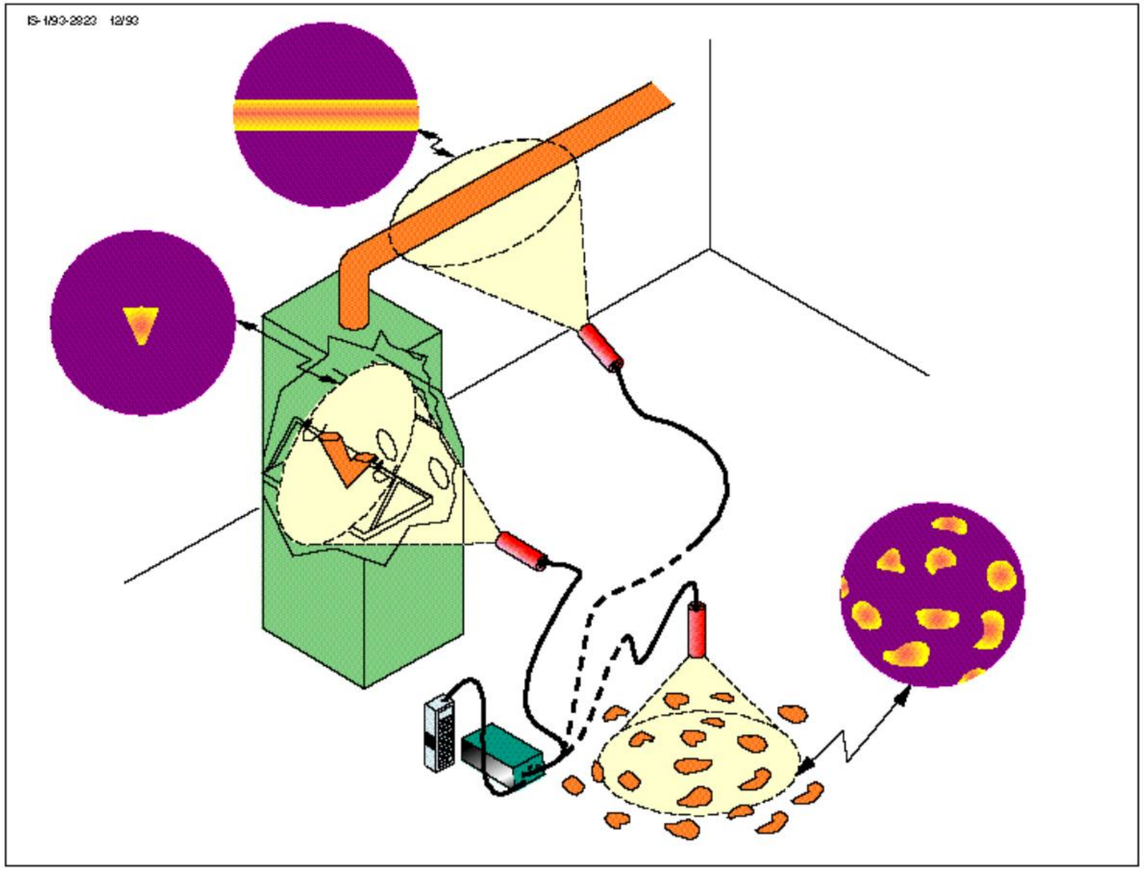
Holdup???



ASTM International C 1673 – 07 Standard Terminology of C26.10 Nondestructive Assay Methods

Holdup — the residual nuclear material remaining in process equipment and facilities.

Generalized Geometry Holdup Model



The process equipment containing SNM is modeled as a point, line, or area geometry for measurement.

Expected Regions of High Holdup

- Pipes and Ducts
  - Elbows
  - Junctions
  - Seams
  - Changes in diameter
  - Regions of low or stagnant flow

- Air Filters
  - Impedance to air flow
  - Particulate barrier

- Heavy Equipment
  - Impeller blades
  - Furnace entrances
  - Storage tanks
  - Dissolver trays

Features of a Typical Plant Prone to SNM Holdup

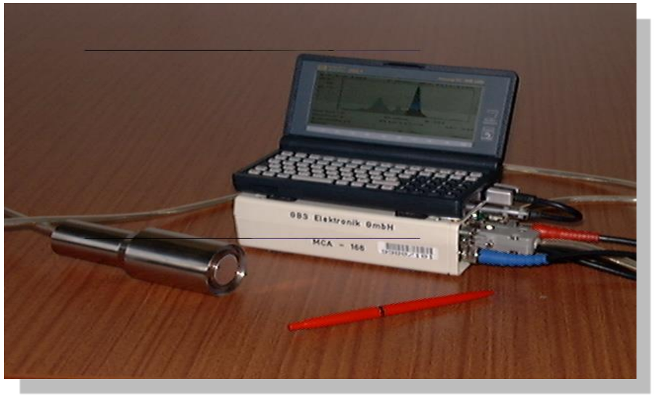
1. Pipes	1000 km
2. Valves	10,000
3. Storage tanks	300
4. Ductwork	100 km
5. Glove Boxes	300
6. Air Filters	500
7. Settling Ponds	10

etc., etc., ...

Detectors

Detector systems need to be compact, light

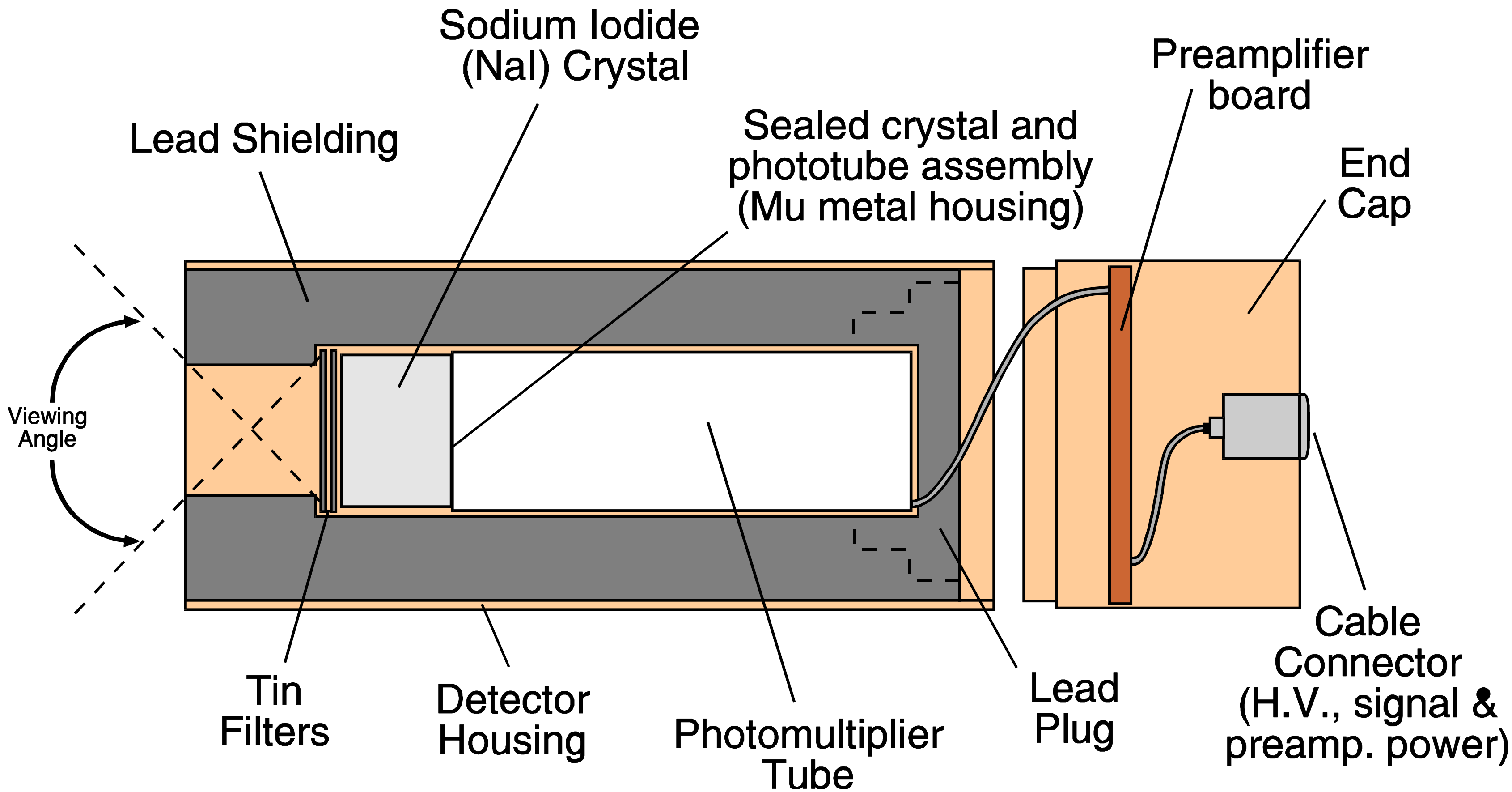
- NaI
  - Portable and light
  - Useful for measuring pipes and ducts
  - Low resolution
  - Works well with uranium



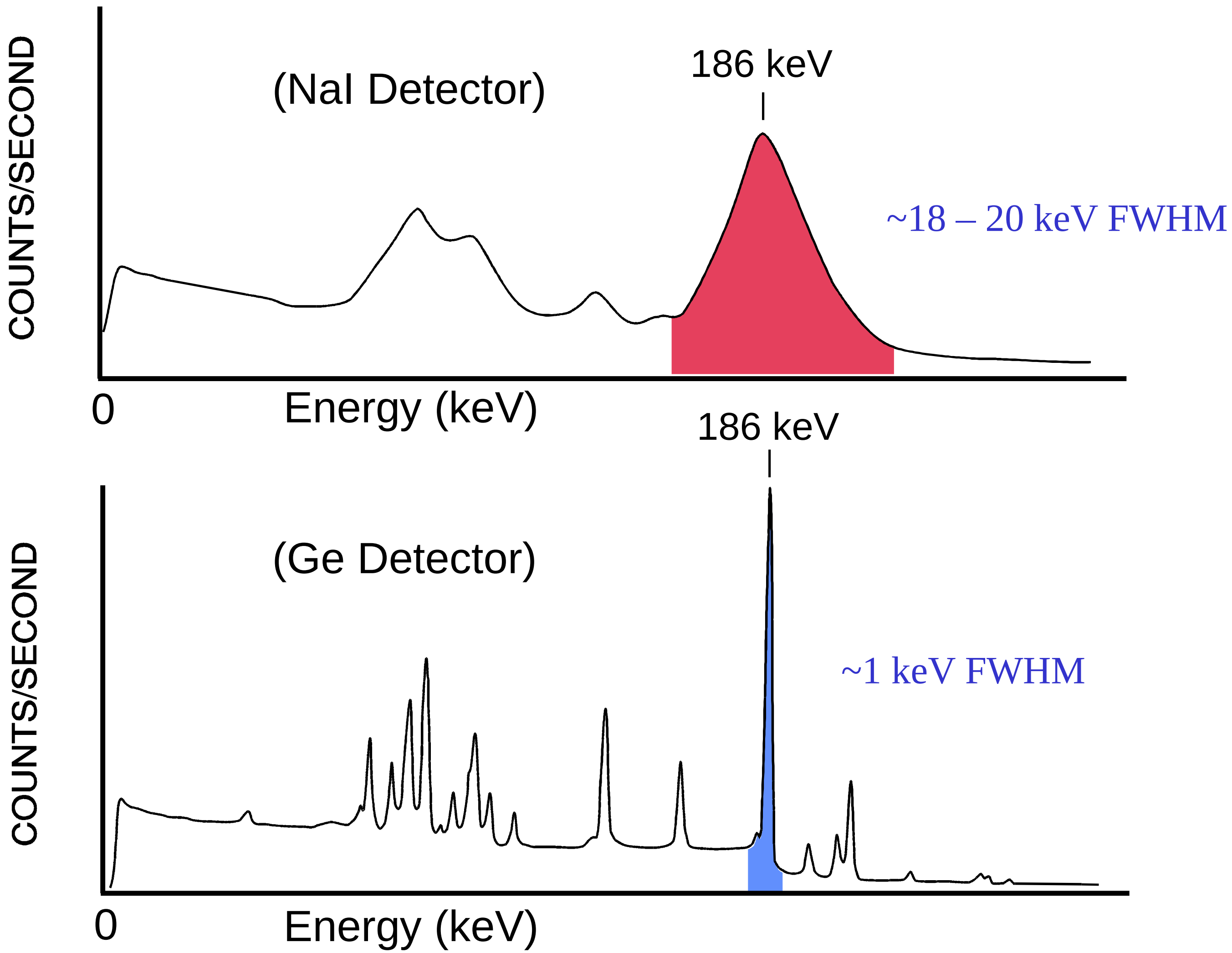
- HPGe (Electrically cooled)
  - Portable but not so light
  - Good for measuring point sources
  - High resolution
  - Works well with uranium and plutonium

HOLDUP MEASUREMENTS

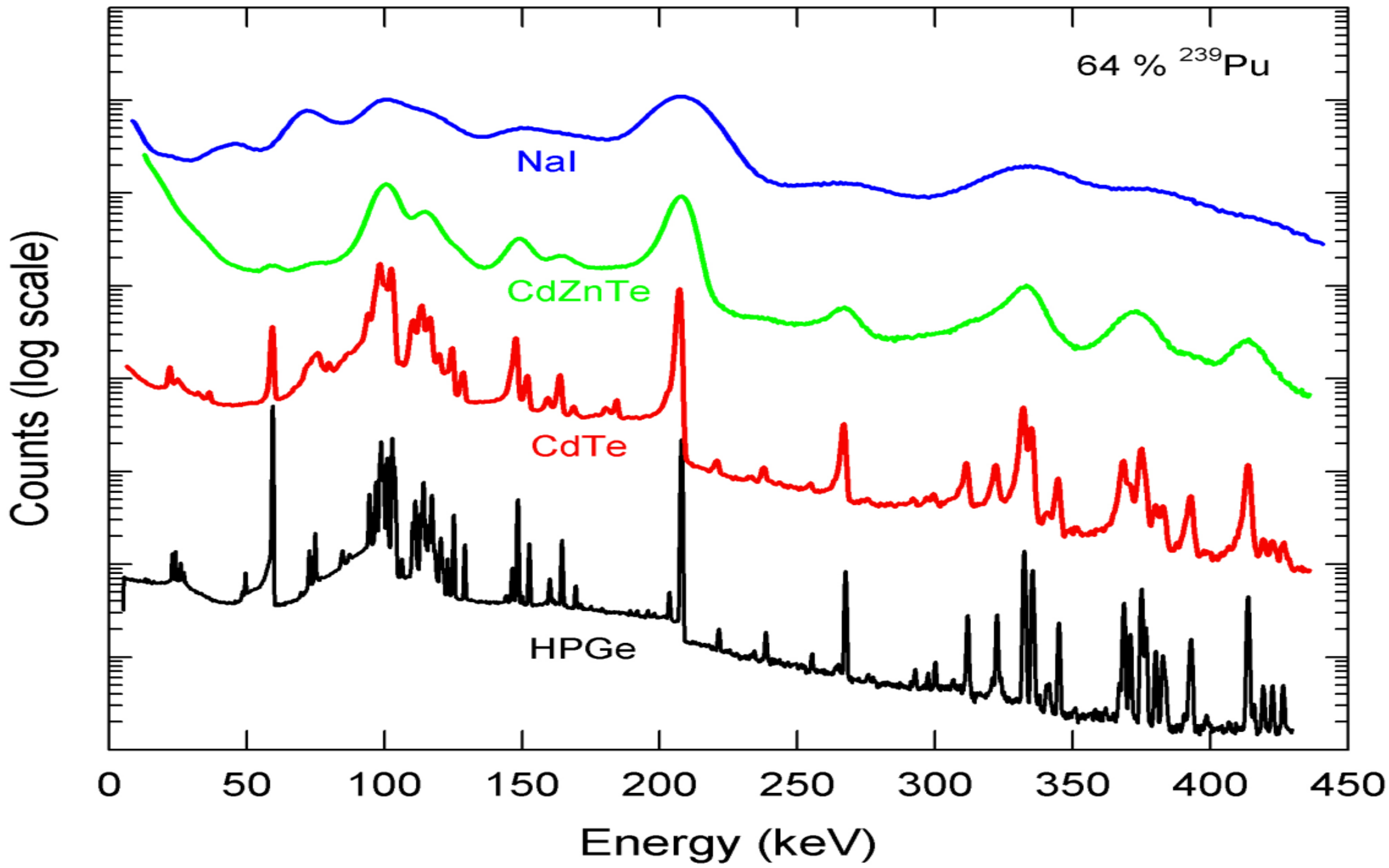
NaI detector for holdup



93.15% ^{235}U Gamma-Ray Spectra



Plutonium spectra



^{239}Pu holdup peaks at ~400 keV

Difficult Holdup

- For some situations, the standard holdup (Generalized Geometry Holdup Model) techniques do not work well.
  - Large facility
  - Facility has penetrating peaks from the background that can interfere with the measured peaks
  - The holdup material is present (or not present) unevenly throughout the room or facility
  - Quantification of dispersed contamination
- Need different, non-standard holdup technique

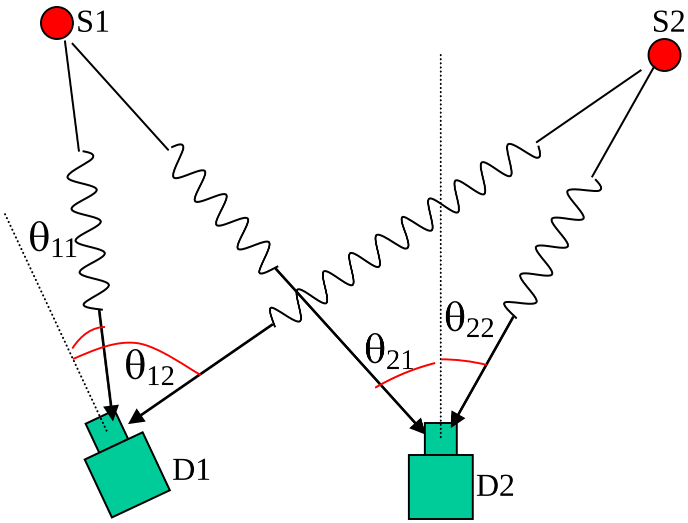
What is Room Holdup Measurement?

- It is a technique that use a non-shielded portable HPGe detector to measure the activity of the holdup in a room.
- It can measure any radionuclides that have measurable gamma rays.
- It uses many peaks from a single or multiple radionuclides in the measurement
  - Pu-239: 129, 203, 345, 375, 414, 452, 646, 769 keV peaks
- It can measure many radionuclides at one time
- It does not require background subtraction
  - Unless the measured gamma rays of a radionuclide are also present in the background radiation (such as those of thorium isotopes)
  - Gamma rays from sources at other locations in the same room are not consider background.

When to use Room Holdup measurements?

- The standard holdup techniques are ineffective
- Only a rough estimation of the total nuclear material in a room or facility is required
- Quick measurements of a room or facility to verify that it is clean or the radioactive activity is insignificant or below a certain level
- When precision can be sacrificed for reduced measurement time
- When the location(s) of holdup are unknown

Principle of the room holdup technique



- Two sources at locations S_1 & S_2
- Two spectra are acquired at locations D_1 & D_2.
- The equations for the peak rates (of a peak) measured at the 2 locations D_1 & D_2 are

$$R_{D1} = R_{S1}\varepsilon_{\theta_{11}} / r_{11}^2 + R_{S2}\varepsilon_{\theta_{12}} / r_{12}^2$$
$$R_{D2} = R_{S1}\varepsilon_{\theta_{21}} / r_{21}^2 + R_{S2}\varepsilon_{\theta_{22}} / r_{22}^2$$

- The peak rates emitted by the 2 sources at locations S_1 & S_2 can be calculated.

Activity Calculation

- Arbitrarily assume that all the activities of the radionuclides are distributed in some way in the ductwork or on the wall, floor, and ceiling of a room.
- The gamma rate $\boldsymbol{R_i}$ measured by the detector at position $\boldsymbol{i}$ is

$$R_i = \sum_j R_{i,j} = \sum_j R_j \varepsilon_\theta / r_{i,j}^2$$

  - $\boldsymbol{i}$ denotes the detector positions of different measurements,
  - $\boldsymbol{j}$ denotes the assumed point source positions,
  - $\boldsymbol{R_j}$ is the rate of the gamma ray emitted by the point source at position $\boldsymbol{j}$,
  - $\boldsymbol{R_{i,j}}$ is the peak rate in the detector at position $\boldsymbol{i}$ from source $\boldsymbol{j}$,
  - $\boldsymbol{r_{i,j}}$ is the distance between the detector at position $\boldsymbol{i}$ and source $\boldsymbol{j}$,
  - $\boldsymbol{\varepsilon_\theta}$ is the detector angular efficiency at 1 m.

Activity Calculation cont.

- For n number of measurements in the room, there will be n equations that need to be solved simultaneously to obtain $\boldsymbol{R_j}$, the rate of the gamma ray emitted by the point source at position $\boldsymbol{j}$
- The total activity of a radionuclide is then

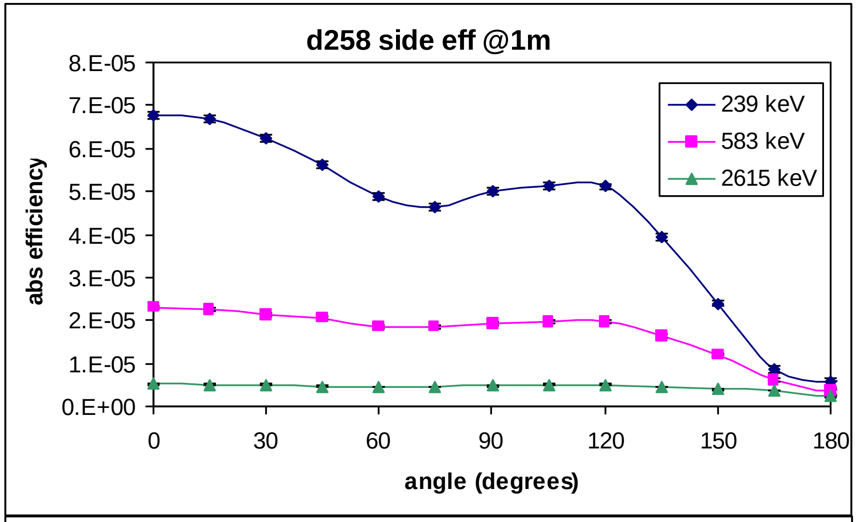
$$A = \frac{R}{Br} = \frac{1}{Br}\sum_j R_j$$

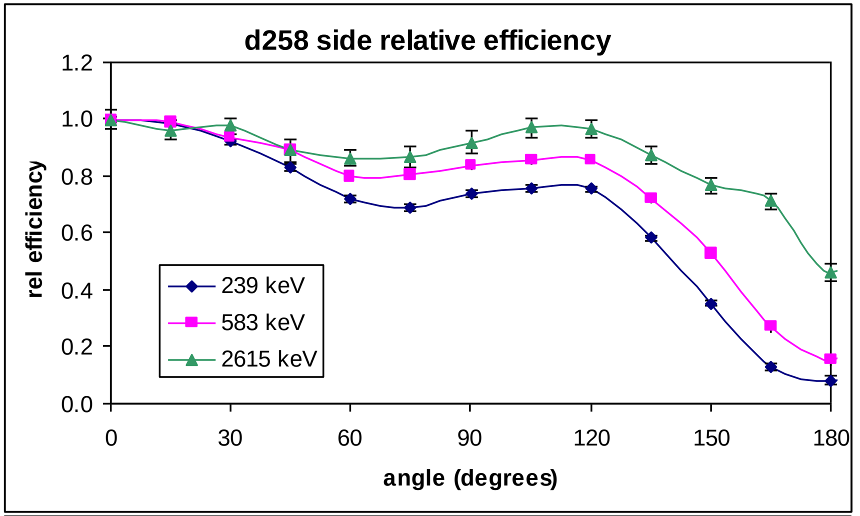
  - ***R*** is the rate of the gamma ray in the room
  - ***Br*** is the branching ratio of the peak

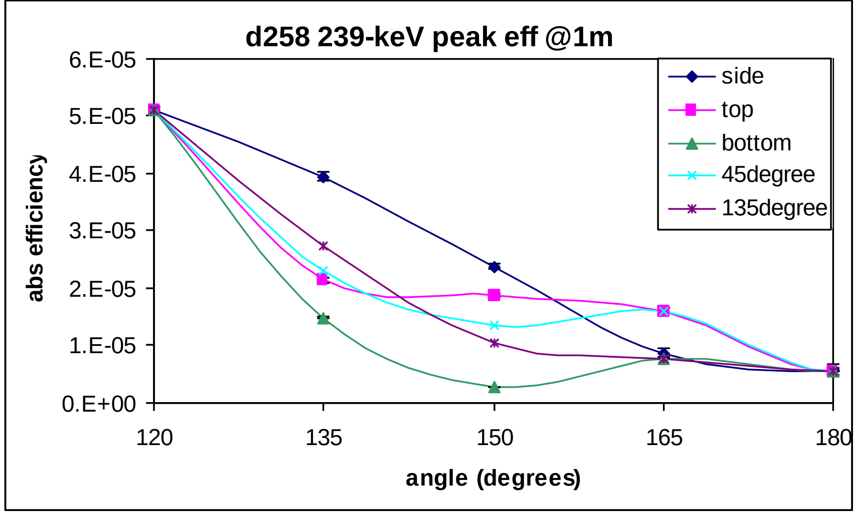
Angular Efficiency Calculation

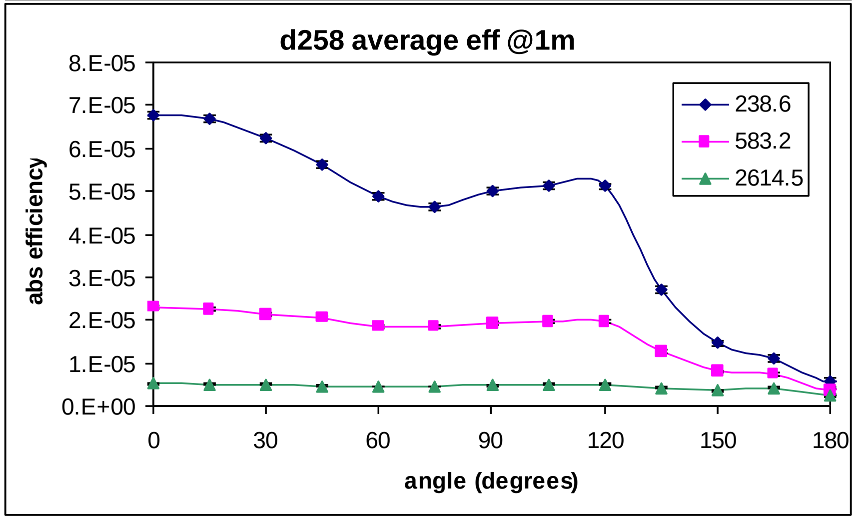
- The angular efficiencies of the detector can be measured using standard calibration sources. The ^{228}Th source, which has three major gamma rays at 238.6, 583.2, and 2614.5 keV, is a good source to use.
- From the efficiencies of these three gamma rays, the efficiency of any other gamma rays can be calculated from about 150 keV up to 3 MeV by interpolation or extrapolation.
- For efficiency below 150 keV, additional ^{228}Th peaks in the X-ray region or a second standard can be used.
- The angular efficiency is measured at 15-degree intervals along the horizontal, vertical, and diagonal planes with respect to the horizontally sitting detector to obtain the 4-π geometry efficiency.

Angular Efficiency of the Ortec Detective SN258









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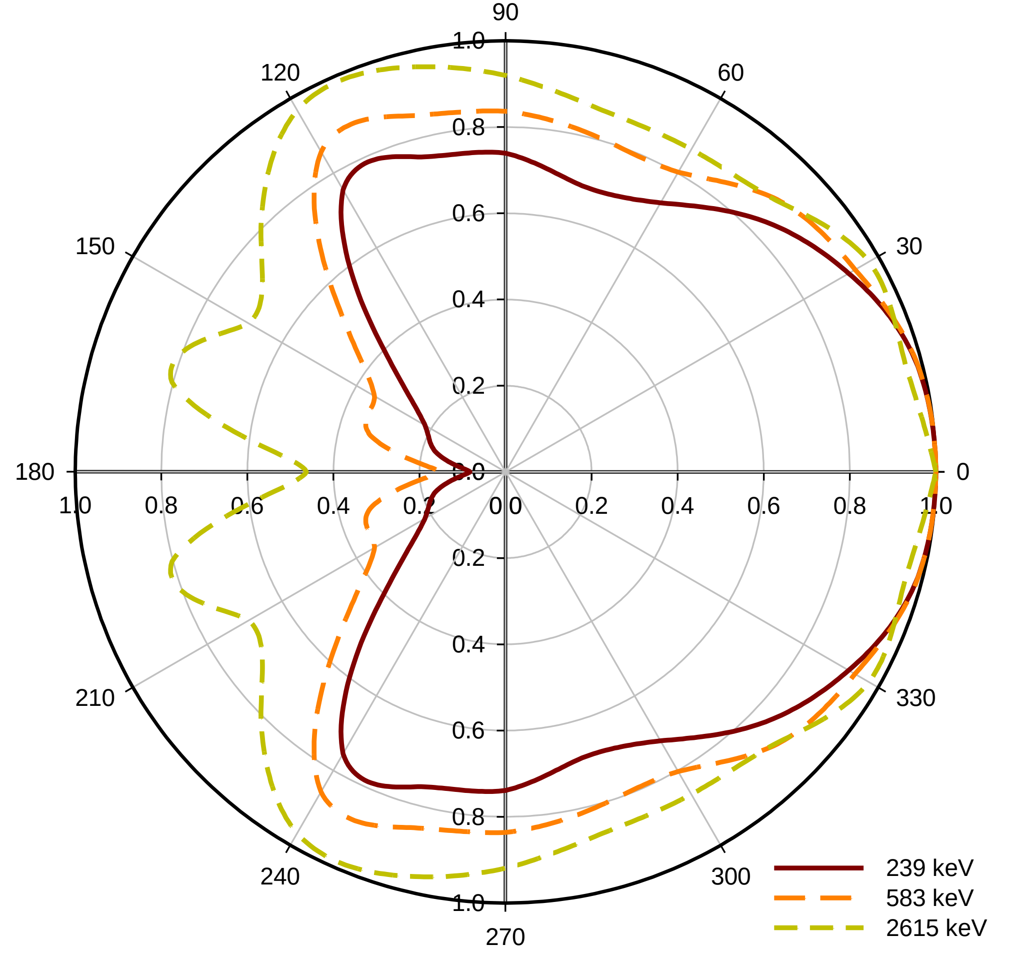
Angular Efficiency: Polar plot

- Polar plot makes it easy to visualize the magnitude of the efficiency at different angles.

Detective 258 relative angular efficiency



Attenuation Corrections

- Because the chemical and physical configurations of the radionuclides are generally not known, correction for self-absorption cannot be made.
- Given that the material is in the form of holdup and contamination, the self-absorption effects should be small.
- The assumption is that all the absorption comes from an external absorber.
- The external attenuation can be estimated using the results of the multiple peaks of a nuclide.

Attenuation correction calculation

- The equation for the absorber thickness is

$$x = -\frac{\ln(T_2/T_1)}{\mu_2 - \mu_1} = -\frac{\ln(A_2/A_1)}{\mu_2 - \mu_1}$$

  - x is the absorber thickness,
  - T_i is the transmission probability of the gamma ray i passing through the absorber,
  - A_i is the activity of the isotope measured by the gamma ray i ,
  - μ_i is the attenuation coefficient of the absorber (assumed to be iron) at the energy of the gamma ray i,
  - gamma rays 1 and 2 are from the same isotope.
- The true activity measured by a gamma ray is then

$$\boldsymbol{A}_{\text{true}} = A_{\text{meas}} \exp(\mu x)$$

How are the measurements done?

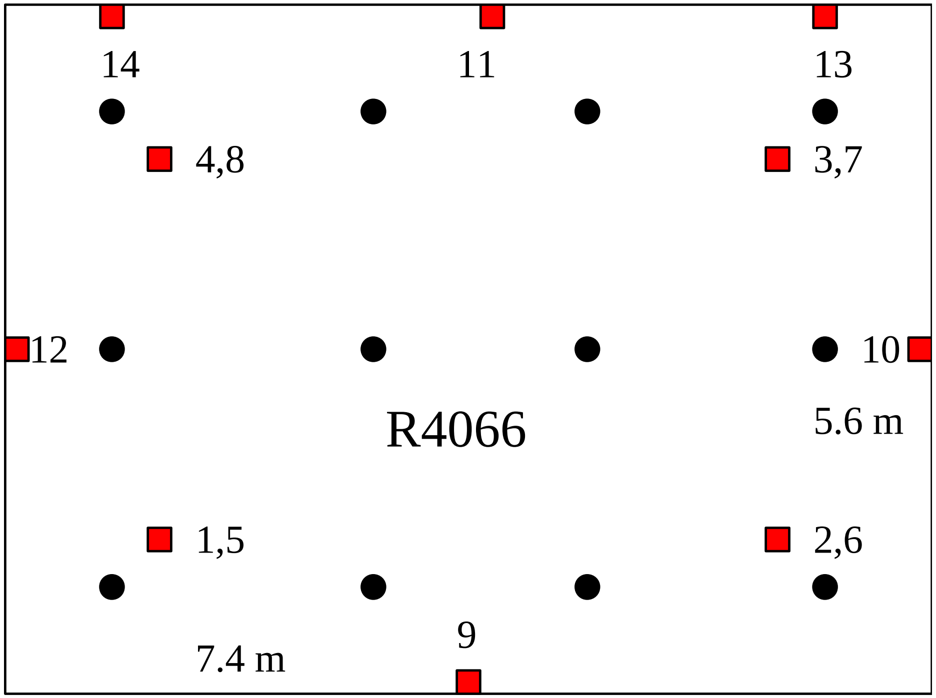
- Many spectra are measured at various positions in a room (at about 6-12 ft interval). The detector may be (but not necessary) pointed at where the radioactive material is thought to be present.
- The peak areas are then obtained from the spectra.
- The locations of the holdup are assumed to be somewhere in the room.
- From the peak intensities measured at various locations and the assumed source locations, the activities at individual locations and total activity of the radionuclide can be calculated.

Measurements

- How to optimize the measurements?
  - More measurements near source locations and less at locations far away from sources.
  - In general, regularly spaced measurements would be reasonable and would simplify the calculations.
- What direction should the detector be pointed?
  - For the best results, the detector should point in the direction where the peak rate is most intense.
  - In practice, it is easier to setup the equations and to calculate the activity if the detector is pointed upward (in the Z direction) or horizontally (in either the X or Y direction).
  - It is also easier to acquire data with the detector points in either the X, Y, Z direction.
- Where should the initial source locations be assigned?
  - At locations where the presence of nuclear material is known.
  - At roughly evenly distributed locations around a room.

Example – CMR Wing 4, room 4066

- The black circles represent the detector positions.
- The detector is pointing upward in the z direction.
- The detector crystal was 1.25 m above the floor.
- The sources are initially assumed to be at locations 1–12 (red squares)
  - Positions 1–4 are located on the ceiling
  - Positions 5–8 are located on the floor
  - Positions 9–12 are placed on the four walls at the midpoints of the walls—1.6 m above the floor



- After initial analysis, 2 more sources are added at positions 13 and 14 (also 1.6 m in the z direction)
- Some sources may also be allowed to vary their positions